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LIGHT INTENSITY AND DEPTH PERCEPTION.

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In a former article the writer described some experiments in connection with the "paradoxical experiment" of Fechner, made in the psychological laboratory of the University of Toronto, with the purpose of investigating the relation of the light intensities of monocular and binocular vision. It was found that the relation could not be very definitely determined, not only because of the variability of the subjective conditions which largely affect it, but also because it depends in great measure upon the absolute light intensity of the object or objects observed. The results, however, suggested some further inquiries, which have been pursued by a method which the present article is an attempt to describe.

The "paradox" of Fechner consists in the fact that when one eye is partially obscured by a smoked glass or other means, the closing of that eye results in a *brightening* of the common visual field, or of an object in the common visual field; *i. e.*, a decrease of intensity of physical stimulus results in an increase of intensity of sensation.

Aubert, following Fechner, found that at a certain degree of obscuration of the second eye occurred the greatest darkening of the common visual field, and that the admission of less light to that eye had then the same effect as the admission of more light, *viz.*, a brightening of the common visual field. This point of greatest darkening Aubert calls the "minimum point," and above and below it are "conjugate points," where the admission of a small or a large degree of light has the same effect upon the brightness of the total visual field.

My own experiments showed that the paradoxical phenomenon occurs only when most of the light is excluded from the second eye. If, on the other hand, comparatively little light is excluded, on the closing of that eye the whole visual field appears darker. Between these limits there is for every absolute intensity what may be called an "indifference point," or point of inefficiency, at which the light admitted to the

second eye has no effect upon the brightness of the common visual field, or of an object in the common visual field.

Dr. Kirschmann, in a comment upon the writer's experiments and their results, as published in a former number of the JOURNAL, offered two suggestions as furnishing a problem for further investigation: (1) That where the paradoxical phenomenon occurs, it is due to the fact that the physical energy which reaches the retina of the partially obscured eye is less than the energy required for combining the two impressions and localizing them in the third dimension. In that case, part of the energy communicated to the retina of the free eye may be subtracted to aid the other eye in producing the binocular combination; then, on the closing of the other eye, this part of the energy would be set free and the result would be an increase of the light intensity. (2) That the "conjugate points" of Fechner and Aubert may be accounted for by the assumption that where one of the monocular intensities is very low, while the other is comparatively high, the binocular combination does not take place. Thus Aubert found the point of greatest darkening where, the light admitted to the undarkened eye being represented by 1000, 122 parts were admitted to the other eye. If this were the lowest point at which the stereoscopic effect is produced, then below it all the light admitted to the second eye would go to increase the light intensity, and, similarly, above it the additional light would have that effect.

Taking, then, these suggestions in connection with the results of previous investigations as a starting point, the experiments which this article describes had for their object to determine the least amount of light which must be admitted to the second eye to produce the stereoscopic effect, and to find whether or not that amount of light corresponds to the amount which is inefficient as regards the comparative light intensities of monocular and binocular vision. If the first of the above suggestions were correct, we should expect to find that the maximum of light which can be admitted to the partially obscured eye without increasing the total brightness, approximates to the minimum of light required in that eye to produce the stereoscopic effect. If the second suggestion were correct, we should expect that the stereoscopic effect would not appear below the "minimum point" of Fechner and Aubert, *i. e.*, where less than 0.122 of the full light was admitted to the second eye.

The apparatus used is shown in the accompanying plate (Fig. 1). Though simple in appearance when completed, and very easily manipulated, its construction required much care. It was manufactured especially for this research from

a design furnished chiefly by the director of the laboratory, Dr. Kirschmann, to whom also thanks are due for valuable suggestions and assistance throughout the investigation. In front are two stereoscopes, the inner lens of each of which may be closed by means of a small shutter. Behind these is an episkotister disc turned by an electric motor; this disc is graduated in 360° and arranged so as to vary the light admitted between the limits of 0° and 270° . The stereoscopes are arranged before the episkotister in such a way that one eye looks at the object directly, the other through the revolving disc. Immediately behind the disc is placed a black velvet screen with two openings on each side, opposite the lenses of the stereoscopes. Behind this again at the focal distance of the stereoscopes, is a second black screen, on which are fixed the objects to be observed. The objects chiefly used were four small squares of white cardboard placed before each stereoscope, with right-lined figures drawn, as in Fig. 2, so that when combined they present the appearance of two pyramids, one above the other, the apex of the upper one projecting towards the observer, that of the lower one receding, and thus presenting the appearance of a hollow passage. By the use of *two* sets of objects and *two* stereoscopes, there were avoided possible errors which might arise (1) from a difference between the two eyes of the observer; (2) from a difference in the treatment of the two eyes throughout the experiments. The purpose of using two pyramids on each side was to afford an indubitable criterion of the binocular combination. This criterion consists in the small squares which form the summit of the pyramids being seen in the middle of the larger squares and vertically one above the other. Such a criterion is necessary, because as the light admitted to one eye is gradually decreased by means of the episkotister, the binocular combination does not at a certain point suddenly cease, but becomes gradually less and less complete, until at length it ceases to be perceptible. It was found necessary to use the simplest outline drawing possible, as photographs, etc., have, even when looked at with one eye, a certain depth effect, dependent, of course, on secondary factors of depth perception, which made discrimination more difficult.

The observer looks alternately through the right and left-hand stereoscopes, and after each double trial¹ readjusts the episkotister so as to admit more or fewer degrees of light, and continues thus till there are found (1) the lowest point

¹This does not imply a perfectly conscious method, as the observer was unaware of the absolute intensity.

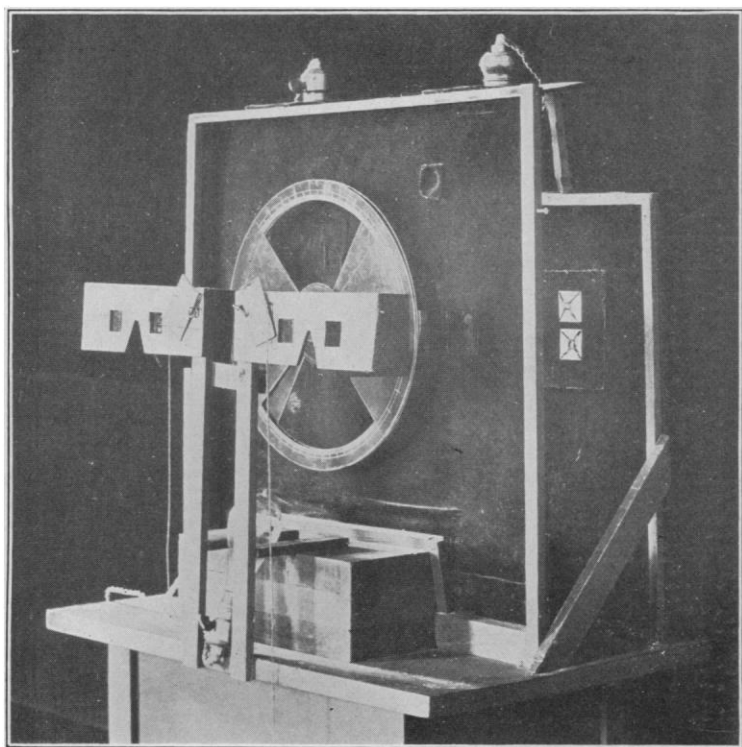


FIG. 1.

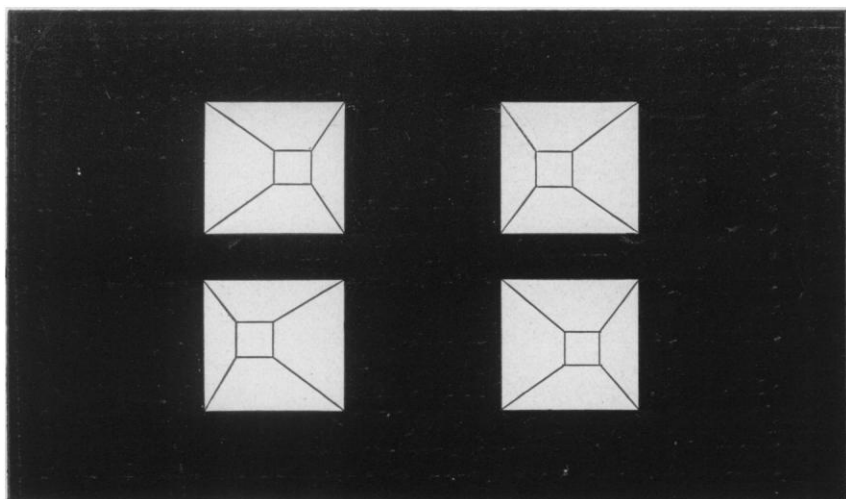


FIG. 2.

at which the objects continue to be completely combined, and (2) the point at which there is no longer any combination at all. The shutter is used to close one lens of the stereoscope so as to compare the monocular and binocular effects. The "indifference point" of light intensity is found, according to the method described fully in the former article, by first looking through the stereoscope at the objects and then excluding one eye by means of the shutter, and after each trial readjusting the disc until a point is reached where no difference in brightness is observable, whether the object is regarded with one eye or both. The adjustment of the episkotister was facilitated by the use of the incandescent lamp, shown in the front of the figure, between the supports of the stereoscopes. This light was turned off during the trials, and when in use screened from the eyes of the observer. The screen used for this purpose, as well as the black velvet covering kept over the apparatus when in use, is not shown in the figure, in order that all parts of the apparatus might be more distinctly visible. Each set of objects was lighted by an electric lamp suspended between the screens, and the intensity was varied by using lamps of different candle power, or by placing sheets of tissue paper around the lamps. All the experiments were conducted in a dark room. Owing to the number of trials required, it was not possible to secure series of trials from many observers, but those obtained had the advantage of being made by persons accustomed to psychological experimenting, the observers, besides the investigator, being Mr. W. B. Lane, M. A., a fellow graduate student, who was conducting some researches in the laboratory; Dr. Kirschmann, and Mr. A. H. Abbott, B. A., assistant in the laboratory. The writer desires to express his indebtedness to the kindness of these gentlemen, especially Mr. Lane, who devoted much time to patient observation. The results of the trials are shown in the following tables.

TABLE I. OBSERVER R.

DESCRIPTION OF LIGHT USED.	PHOTOMET- RICALLY DE- TERMINED IN- TENSITY OF THE LIGHT.	MINIMUM AMOUNT OF LIGHT NECESSARY FOR THE SECOND EYE IN ORDER TO OBTAIN COMPLETE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SEC- OND EYE INEFFICIENT FOR THE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SEC- OND EYE INEFFICIENT FOR THE BRIGHTNESS OF THE COMBINED VISUAL FIELD.		
		a.	b.	c.	a.	b.	c.	a.	b.	c.
		In degrees of the Episko- tister.	In units of intensity.	Ratio of the inten- sity for the other eye.	In degrees of the Episko- tister.	In units of intensity.	Ratio of the inten- sity for the other eye.	In degrees of the Episko- tister.	In units of intensity.	Ratio of the inten- sity for the other eye.
8 c. p. lamp + 34 t. p.	1	147°	.41	.41	85°	.18	.18	151°	.41	.41
8 c. p. + 26 t. p.	2.77	85°	.65	.23	48°	.37	.13	157°	1.21	.43
" 20 "	3.88	65°	.70	.18	32°	.55	.09	156°	1.68	.43
" 16 "	6.66	66°	1.31	.19	30°	.64	.08	174°	3.23	.48
" 12 "	16.16	47°	2.09	.12	14°	.85	.02	197°	9.12	.56
" 8 "	29.16	32°	2.59	.08	10°	.90	.01	175°	14.17	.48
" 4 "	56.94	19°	3.04	.05	5°	.74	.007	174°	27.51	.48
8 c. p.	100.00	12°	3.47	.03	2°	.80	.004	145°	38.20	.38
16 "	192.00	10°	5.53	.02	1°	1.10	.002	126°	67.69	.35
32 c. p. + 4 t. p.	527.70	12°	17.59	.03	* 5° (?)	2.80	.001	103°	145.91	.27
32 c. p.	1,014.80	5°	14.09	.01	* 3° (?)	2.17	.0006	117°	330.54	.32
50 "	1,615.70	3°	14.03	.009	* 1° (?)			90°	381.93	.25
100 "	3,130.40	5°	46.37	.01				82°	719.98	.22

* A partial stereoscopic effect sometimes remained at a point lower than the disc was graduated to measure.

TABLE II. OBSERVER L.

DESCRIPTION OF LIGHT USED.	PHOTOMET- RICALLY DE- TERMINED IN- TENSITY OF LIGHT.	MINIMUM AMOUNT OF LIGHT NECESSARY FOR SECOND EYE IN ORDER TO OBTAIN COMPLETE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SEC- OND EYE INEFFICIENT FOR THE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SEC- OND EYE INEFFICIENT FOR THE BRIGHTNESS OF THE COMBINED VISUAL FIELD.		
		a.	b.	c.	a.	b.	c.	a.	b.	c.
		In degrees of the Epis- koustler.	In units of intensity.	Ratio of the inten- sity for the other eye.	In degrees of the Epis- koustler.	In units of intensity.	Ratio of the inten- sity for the other eye.	In degrees of the Epis- koustler.	In units of intensity.	Ratio of the inten- sity for the other eye.
8 c. p. lamp	1	225°	.62	.62	114°	.31	.31	2297°	.63	.63
+ 34 t. p.	2.77	176°	1.35	.48	42°	.32	.11	1691°	1.26	.45
8c.p.+26t.p.	3.88	102°	1.02	.26	26°	.28	.07	1772°	1.91	.49
" 20 "	6.66	93°	1.72	.25	16°	.30	.04	1563°	2.89	.43
" 16 "	16.16	80°	3.59	.22	9°	.43	.02	1761°	7.21	.44
" 12 "	29.16	341°	2.76	.09	10°	.83	.02	1733°	14.07	.48
" 8 "	56.94	421°	6.70	.11	4°	.67	.01	1864°	28.52	.50
" 4 "	100.00	281°	7.87	.07	2°	.78	.007	190°	52.77	.52
16 "	192.00	221°	12.00	.06	1°	.89	.004	14611°	78.28	.40
8 c. p.	527.70	5°	7.32	.01	2°	.73	.001	4972°	142.91	.27
32c.p.+4t.p.	1,014.80	7°	19.73	.01	* 1° (?)	.73	.0007	19011°	537.75	.52
32 c. p.	1,515.70	81°	37.36	.02	* 1° (?)	.84	.0005	15611°	657.50	.43
50 "	3,130.40	151°	136.95	.04	* 2° (?)	7.61	.0002	17310°	1,505.58	.48

* A partial stereoscopic effect sometimes remained at a point lower than the disc was graduated to measure.

† Result of only one series.

TABLE III. OBSERVER K.

DESCRIPTION OF LIGHT USED.	PHOTOMET- RICALLY DE- TERMINED IN- TENSITY OF LIGHT.	MINIMUM AMOUNT OF LIGHT NECESSARY FOR SECOND EYE IN ORDER TO OBTAIN COMPLETE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SEC- OND EYE INEFFICIENT FOR THE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SEC- OND EYE INEFFICIENT FOR THE BRIGHTNESS OF THE COMBINED VISUAL FIELD.		
		a.	b.	c.	a.	b.	c.	a.	b.	c.
		In degrees of the Episko- tister.	In units of intensity.	Ratio of the inten- sity for the other eye.	In degrees of the Episko- tister.	In units of intensity.	Ratio of the inten- sity for the other eye.	In degrees of the Episko- tister.	In units of intensity.	Ratio of the inten- sity for the other eye.
8 c. p. lamp	1	110°	.30	.30	70°	.19	.19	+Undecided.		
+ 34 t. p.	2.77	63°	.45	.16	47°	.36	.12	164 $\frac{1}{2}$ °	1.41	.50
8 c.p.+26t.p.	3.88	50°	.53	.13	31°	.33	.08	166 $\frac{1}{2}$ °	1.79	.46
" 20 "	"	29°	.55	.08	14°	.25	.03	180 $\frac{1}{2}$ °	3.33	.50
" 16 "	6.66	23°	1.03	.06	9°	.40	.02	172 $\frac{3}{4}$ °	7.73	.47
" 12 "	16.16	15°	1.21	.04	3°	.24	.008	246 $\frac{3}{8}$ °	19.92	.62
" 8 "	29.16	11°	2.37	.04	3 $\frac{1}{2}$ °	.55	.009	170 $\frac{1}{2}$ °	27.02	.47
" 4 "	56.94	11°	3.05	.03	2 $\frac{1}{2}$ °	.69	.006	131 $\frac{1}{2}$ °	36.57	.36
8 c. p.	100.00	11 $\frac{1}{2}$ °	6.13	.03	2 $\frac{1}{2}$ °	.26	.001	148 $\frac{1}{2}$ °	79.11	.41
16 "	192.00	2 $\frac{1}{2}$ °	3.66	.006	3°	.73	.001	135°	197.88	.37
32 c.p.+4t.p.	527.70	3°	8.45	.008	*1°(?)	.70(?)	.0006(?)	113 $\frac{1}{2}$ °	320.88	.31
32 c. p.	1,014.80	2°	8.42	.005	*Not found.			128 $\frac{1}{2}$ °	541.32	.35
50 "	1,515.70	1 $\frac{1}{2}$ °	10.86	.003	*Not found.			106 $\frac{1}{2}$ °	926.49	.29
100 "	3,130.40									

*A partial stereoscopic effect remained at a point lower than the disc was graduated to measure.

+On account of the dimness and orange color of the light coming through so many sheets of tissue paper, the monocular and binocular light intensities could not be discriminated very clearly.

TABLE IV. OBSERVER A.*

DESCRIPTION OF LIGHT USED.	PHOTOMET- RICALLY DE- TERMINED IN- TENSITY OF LIGHT.	MINIMUM AMOUNT OF LIGHT NECESSARY FOR SECOND EYE IN ORDER TO OBTAIN COMPLETE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SECOND EYE INEFFICIENT FOR THE STEREOSCOPIC EFFECT.			AMOUNT OF LIGHT FOR THE SEC- OND EYE INEFFICIENT FOR THE BRIGHTNESS OF THE COMBINED VISUAL FIELD.		
		a. In degrees of the Epis- kotister.	b. In units of the in- tensity. Intensity.	c. Ratio of the inten- sity for the other eye.	a. In degrees of the Epis- kotister.	b. In units of the in- tensity. Intensity.	c. Ratio of the inten- sity for the other eye.	a. In degrees of the Epis- kotister.	b. In units of intensity.	c. Ratio of the inten- sity for the other eye.
8 c. p. lamp	6.66	112°	2.07	.31	32°	.59	.08	+192° (?)	3.55	.53
+ 16 t. p.	16.16	90°	4.04	.25	22½°	1.01	.06	+231° (?)	9.87	.61
8 c. p. + 12 t. p.	29.16	110°	8.91	.30	32½°	2.63	.08	217°	17.59	.60
" 4 "	56.94	90°	14.23	.24	25°	3.95	.06	187½°	29.61	.52
8 c. p.	100.00	22°	6.11	.06	9°	2.50	.02	98½°	27.31	.27
16 "	192.00	22°	11.73	.06	9°	4.80	.02	131°	70.00	.36
32 c. p. + 4 t. p.	527.70	55°	75.06	.14	1°	1.46	.002	115°	243.08	.46
32 c. p.	1014.80	9°	25.37	.02	3°	8.45	.008	108½°	306.55	.30
50 "	1515.70	10°	42.10	.02	1½°	6.31	.004	+210° (?)	884.15	.51
100 "	3130.40	50°	434.77	.13	½°	4.34	.001	87½°	761.10	.24

* Owing to special conditions, the trials with this observer were not made with the three lowest intensities.

+ The "equal" limits had not been passed at 135° on the disc.

The intensities of the lights used were measured relatively to each other by means of an episkotister photometer; in the table the intensity of the weakest light, that of an eight-candle power electric lamp, surrounded by thirty-four sheets of white tissue paper, is given as 1, and the others in comparison with it. The results of each observer are exhibited in a separate table. The second main division of the tables shows the lowest point for each absolute intensity at which the stereoscopic effect was complete, the third the point at which it had entirely ceased. Between these points there was a region of partial or incomplete combination. Here the objects were sometimes confusedly intermingled; sometimes the complete stereoscopic effect would alternately appear and disappear, and again there would occur the phenomenon of competition of the vision fields, first one and then another set of lines becoming more distinct. The fourth division of the tables gives for each absolute intensity the amount of light which can be admitted to one eye without producing any change in the brightness of the common vision field. It will be observed that in this division the results are less regular than in the others. This is probably because: (1) The judgments concerning light intensity are more difficult than those concerning the stereoscopic effect, and to secure regularity would require the averaging of a greater number of trials; (2) With the lower intensities the tissue papers gave always a certain degree of color which had to be abstracted from in judging of the brightness, as the color would also change on the closing of the shutter; (3) These difficulties gave rise to a third source of irregularity, viz., that the observer had often to look for some time at the object before deciding, and in those cases, owing to the adjustment of the eyes, the results were probably somewhat different from what they would have been could the judgment have been given immediately. The results, however, appear sufficiently exact for the purpose of our comparison.

It is also noticeable that the results are less regular with very high absolute intensities, probably because these intensities are somewhat near to what, for the eye adapted to the low intensities of the darkened room, forms the "upper limit."

We may now attempt to estimate the significance of our results.

I. The amount of light required in the second eye to produce the stereoscopic effect seems with most of the intensities used surprisingly small. With very high intensities one one-hundredth of the full light, or less, was sufficient to make it complete, while a partial effect in many cases re-

mained with the very least amount which the disc could be adjusted to admit. Where episkotister values of less than 1° are given, no great reliance can be placed on their accuracy, as the disc was not graduated to measure smaller quantities than half a degree with exactness. Where such values are given in the tables, they represent the average of different results, in some of which the lowest intensity measurable was not low enough to make the stereoscopic effect disappear. On the other hand, with the lowest absolute intensities, about one-half the full light was necessary for the second eye in order to produce the complete stereoscopic effect, while for any stereoscopic effect at all, from about one-fifth to one-third of the full light was required. In connection with these results two problems are presented: (1) To account for the great difference between the proportion of light required for the second eye at low absolute intensities, and that required at high intensities. (2) To account for the wide range in all cases between the point where the objects begin to combine, and the point where the complete stereoscopic effect is obtained. The amount of light at the latter point is about from two to twenty times as great as at the former.

With regard to the first of these questions, there seems to be something more involved than mere proportionality; for while the amount of light required for the second eye increases regularly with the increase of the absolute intensity, the increase is not *proportionate*; so far from it, indeed, that the ratio of the intensities for the darkened and the undarkened eyes, instead of increasing or remaining constant, decreases so rapidly that it is from fifteen to one hundred times smaller at the highest than at the lowest intensities. This would seem to suggest that the coöperation of the two retinas in producing the binocular combination, is of so intimate a character that where one retina is not stimulated sufficiently to enable it to play its part in that combination, its energy may be supplemented by that of the other. If that be so, then naturally the greater the amount of light admitted to the free eye, the greater will be the energy which can be spared to supplement that of the partially darkened eye, and consequently the smaller the proportion of light required in the latter for the binocular combination. This point will be discussed more fully further on, but it may be noted here that by the *binocular* combination is not meant the *stereoscopic* combination. The factors of binocular depth perception are of course such that in it one eye cannot do any part of the work of the other. But in order to the production of the stereoscopic effect, it is first necessary that the two images should be combined so as to present the appearance

of a single surface ; and it is in this combination that the interpretation of our results seems to require the assumption that part of the energy of the retina of the free eye is directed to aiding the other retina. This hypothesis is supported by, and at the same time affords an explanation of, the second fact above noted, viz., that the amount of light admitted to the second eye at the point where the objects begin to combine is only a small fraction of that required for the complete stereoscopic effect. For if in the former case only the coincidence of surfaces takes place, and in that the free eye can aid the other, while in the latter there occurs the complete stereoscopic combination, it is evident that in the latter case the aid which the free eye can render to the other is proportionately much smaller, and consequently the proportion of light required in the second eye much greater than where the objects combine only as in a plane surface. This distinction of the binocular from the complete stereoscopic combination is not a merely hypothetical one, as throughout the course of the experiments it was frequently noted that the objects would coincide as a single surface where there was no depth effect perceptible.¹ In this case the lines did not combine, and, for the observer *L.* especially, one of the criteria for the completeness of the stereoscopic combination was that as soon as it began to be incomplete, he had "double images" of the small central squares.

II. The "indifference point," or point of inefficiency as regards the comparative light intensities of monocular and binocular vision, varies also in correspondence with the absolute intensity ; the amount of light which can be admitted to the second eye without affecting the brightness of the common visual field increases regularly with the increase of the absolute intensity. The ratio of the amounts of light admitted to the obscured and the unobscured eyes shows, however, at this "indifference point" less variation than at the lowest point of effectiveness for the stereoscopic combination. In this connection there are three points which seem to require explanation : (1) That so large a proportion of the full light, varying, with different absolute intensities and different observers, from about one-fifth to nearly two-thirds, can be admitted to the second eye without increasing the total brightness ; (2) That while the amount of light for the second eye is inefficient for the brightness of the combined visual

¹ For the further elucidation of this point, *i. e.*, the possibilities of binocular combination, *vide* the tables appended to Dr. Kirschmann's article on "Metallic Lustre and The Parallax of Indirect Vision," *Philos. Studien*, Vol. XI, 1895, pp. 147-189.

field increases in quite regular correspondence with the absolute intensity, the increase here, as with the light required in the second eye for the stereoscopic effect, is not proportional, so that while the actual amount of light increases, the ratio to the full light continuously decreases; (3) The paradoxical phenomenon, viz., that below the "indifference point" the closing of the partially darkened eye causes a brightening of the common visual field, *i. e.*, a decrease of intensity of physical stimulus results in an increase of intensity of light sensation. With regard to the first of these points it is only necessary to recall the fact that the purpose of the two eyes is not to increase the intensity of light sensation, but to localize objects in space. The second and third points are somewhat closely related, and will be dealt with together in the next paragraph.

III. What is the bearing of our conclusions upon the two suggestions which formed the starting point of the investigation?

1. With reference to the suggested explanation of the "paradoxical experiment" of Fechner. If the experiments confirm this suggestion, the explanation of the paradoxical phenomenon will be quite simple: So much of the energy communicated to the retina of the second eye goes to combine the two retinal images and localize in space the combined image, the remainder, subject, of course to the law of Weber, goes to increase the light intensity of the combined visual field; or, where the energy which reaches the second retina is insufficient to produce the stereoscopic effect, part of the energy is subtracted from the other retina to aid in combining the objects, and the result is a darkening of the common visual field. To confirm this suggestion the results should show a practical coincidence of the "indifference point" of light intensity and the lowest point of effectiveness for the stereoscopic effect. Now, on reference to the tables, it will be seen that the "indifference point" is very much higher in nearly all cases than the point below which the stereoscopic effect ceases to be good; the lower the absolute intensity, however, the nearer these points approach each other, and at certain extremely low absolute intensities they practically coincide. This would seem to indicate that the explanation holds good for these low intensities; the question at once arises, "Why not for higher intensities?" This may be explained quite readily on the supposition that at such low intensities as are denoted in the tables by 1 and 2.77, the light which reaches the retina of the unobscured eye is very little more than sufficient to enable that eye to perform its part in the binocular combination. This supposi-

tion is supported by the fact observed throughout the experiments, that with these very low intensities, at the lowest point where the stereoscopic effect was obtained, the outlines of the objects were not clearly visible with the darkened eye alone, while with higher intensities they were visible with the darkened eye below the point where the stereoscopic effect had ceased to appear. Assuming this supposition to be correct, what bearing will it have upon our results? If we take, for example, in Table 1 the absolute intensity 1, we find that the light which must be admitted to the second eye to produce the complete stereoscopic effect is represented by .41, and .41 also represents for the absolute intensity 1 the amount of light for the second eye, which has no effect on the light intensity of the common visual field. If less light than .41 is admitted to the second eye, therefore, we shall have the "paradox," and we shall not have complete, but only partial stereoscopic effect. Why is this? Apparently because the stimulus applied to the second eye in this case is not sufficient to produce the energy required for the stereoscopic effect. Part of the energy appears to be subtracted from the other retina to aid in the binocular combination, and consequently the common visual field is darkened. But because the energy communicated to the free eye is little more than is needed to produce the required effect in it, there cannot, while that eye continues to discharge its function, be sufficient energy withdrawn from it to make up what is lacking in the other eye, and hence the stereoscopic effect remains incomplete. Then taking a higher absolute intensity, say that represented in the table by 100, we find that the amount of light for the second eye required to produce the complete stereoscopic effect is 3.47, while the amount inefficient for the brightness of the combined visual field is 38.20. Now, on our theory it may be held that the energy which reaches the retina of the free eye is in this case more than is required for that eye to play its part in the coöperation of the two eyes, and where the other eye does not receive sufficient for that purpose, enough energy may be subtracted from the free eye to supplement that of the partially obscured eye, and produce the complete stereoscopic effect. This would account for the fact that with all but the lowest intensities, there is a region, growing more extended as the absolute intensity increases, where the paradoxical phenomenon occurs, while yet the stereoscopic effect is completely preserved.

2. With reference to Fechner's and Aubert's "minimum" and "conjugate points," the suggested explanation

was that below the "minimum point," *i. e.*, the point of greatest darkening in the common visual field by the partial obscuration of one eye, there is no binocular combination, so that all the light admitted to the second eye may go to increase the total brightness; while, on the other hand, above that point, the additional light is not needed for the stereoscopic effect, and so may go to increase the light intensity of the combined visual field. This at first seems also to obtain at least a partial support from the results, as at low intensities—in Tables I and II that denoted by 2.77,—the point where the stereoscopic effect ceases to appear, is rather near the "minimum point" of Fechner and Aubert, namely, .122 of the light admitted to the undarkened eye. There does not, however, appear to be in this case any satisfactory explanation of why these points do not coincide as well at higher intensities, so that their practical coincidence at this one intensity may be merely accidental. Moreover, this explanation would require that as the light admitted to the second eye is decreased, the stereoscopic effects continue complete down to a certain point, and below that point entirely disappear. This, as we have seen, is not the case; below the point where the combination ceases to be complete, there is a rather extended region of partial or incomplete combination. The difficulty seems to be that the fixing of the "minimum point" definitely at .122 is itself not to be relied on, for (1) reference to the tables shows that though the ratio to the full light of the light required for the second eye to produce any effect on the total intensity remains within comparatively narrow limits fairly constant, yet on the whole that ratio varies in correspondence with the absolute intensity, and (2) it must be remembered that the "indifference point" is not usually a single definite point, but that there is usually a considerable region within which no difference in the light intensity of an object in the common visual field is observed when the object is regarded alternately with one eye and two, and the figures in the tables represent simply the averages of all the equal cases.

RÉSUMÉ.

I. The amount of light required for the second eye to produce the stereoscopic effect, is, especially with high intensities, very small.

II. The amount required depends on the absolute intensity.

III. There is a considerable range between the lowest

point where the objects combine, and the point where the complete stereoscopic effect is obtained.

IV. The amount of light for the second eye inefficient for the total brightness corresponds to the amount required for the stereoscopic effect only at very low intensities ; at higher intensities it is much greater.

V. The results seem to indicate a coöperation of the two retinas of so intimate a character as to afford a ground for the explanation of Fechner's "paradoxical experiment."

VI. The distinction between simple binocular coöperation and complete stereoscopic combination, noted in the course of the experiments, presents a problem for further research.